

# **BITUMINOUS ROAD SURFACING IN HIGH STRESS AREAS: MALAYSIAN EXPERIENCE**

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## **ABSTRACT**

Past experience with conventional asphaltic concrete in high stress areas whereby the surfacing material is constantly subjected to extremely long loading times of the slow moving heavy commercial vehicles at high surfacing temperatures has indicated shortcomings. This is evident by excessive rutting and shoving that occurs within a short period of time after laying. Under such conditions, conventional bitumen behaves in a viscous manner thus allowing the bituminous material to flow under the high stresses. Consequent reduction in air voids decreases resistance to deformation as the fine aggregates occupy more of the voids thus reducing contact area between the coarse aggregates. This eventually results in structural instability and the surfacing material shears under the traffic loads.

This paper highlights past experience by Public Works Department of Malaysia (JKR) in evaluating various methods in mitigating permanent deformation of bituminous road surfacing in high stress areas since 1989. Several types of bitumen modifier and innovative bituminous mix have been tried in the past and they were shown to exhibit mixed performances. The techniques which are proven or widely known to be effective in mitigating surface distress induced by slow moving heavy vehicles in high stress areas are herein recommended.

## **1.0 INTRODUCTION**

The design of bituminous road surfacing materials for use in high stress areas such as climbing lanes and major junctions is of considerable concern to road pavement engineers. Past experience with conventional Marshall asphalt design mixes has invariably indicated shortcomings when subjected to high traffic stresses even though the mixes are produced to within the required tolerances. This is evident by excessive rutting and shoving that occurs within a short period of time after construction. This type of surfacing failure is due to the extremely long loading times of the slow moving commercial vehicles at high surfacing temperatures. Under such conditions, conventional bitumen behaves in a viscous manner thus allowing the bituminous material to flow under the high traffic stresses. Consequent reduction in air voids decreases resistance to deformation as the fine aggregates occupy more of the voids thus reducing contact area between the coarse aggregates. This eventually results in structural instability and the surfacing material shears under trafficking.

'High stress area' is hereinafter referred to as that part of a road carriageway which is constantly subjected to extremely long loading times of the slow moving heavy commercial vehicles at high surfacing temperatures such as climbing lanes with relatively steep gradients and major junctions.

## **2.0 SURFACE DISTRESS IN HIGH STRESS AREAS**

### **2.1 Mechanism**

Bitumen is a visco-elastic material whose behavior varies from purely viscous to elastic, depending upon loading conditions. Although its presence as a binder in bituminous mixes is usually in a relatively small quantity, it is highly responsible for the visco-elastic

behaviour of the mixes and, consequently, the performance of the surfacing materials. In a simple creep test, a conventional bituminous mix initially shows an instantaneous elastic response in strain upon application of load. As the load is maintained, a further strain takes place but at a decreasing rate caused by the viscous behaviour of the mix. The magnitude of this viscous component of strain increases with both loading time and temperature.

On removal of the load, the elastic strain is recovered instantaneously and some delayed elastic recovery occurs with time. Ultimately, a minute amount of irrecoverable viscous strain remains in the material. It is the gradual accumulation of these minute strains under repeated application of traffic loading which leads to permanent deformation along the wheelpaths, or popularly known as rutting, of bituminous road surfacing.

## **2.2 Possible Solutions**

It is apparent from the manner rutting takes place in bituminous road surfacing in high stress areas that there are three primary factors that influence the severity of such surface distress. These are;

- i. Loading conditions of traffic.
- ii. Rheological properties of bitumen.
- iii. Skeletal structure of aggregates.

As high stress areas such as climbing lanes and major junctions are part and parcel of road geometry, the more viable solution would therefore be the improvement of the last two factors.

### **2.2.1 Improvements of Rheological Properties of Bitumen**

Bahgat and Zawh [1] reported that the resistance to permanent deformation of asphaltic concrete mixes could be substantially increased by using binders with low temperature susceptibility. The temperature susceptibility was found to decrease with higher asphaltene content, and lower resins, wax and oil contents of the binders. Alternatively, binders with reduced temperature susceptibility could be obtained by using modified bitumen.

The rheological properties of bitumen and, consequently, the deformation characteristics of bituminous mixes could also be modified effectively by incorporating small quantities of bitumen additives. The type of additive that is widely used is polymer.

#### **Polymer additives**

By definition, polymer are long, chain-like molecules made from a small molecule viz the monomer, by chemical linking of a large number of monomer molecules together. For example, one molecule of polyethylene can consist of 1000 ethylene molecules joined together in a chain. When added to bitumen, EVA copolymer for instance, can be readily dispersed in. Improvements in the rheological properties of the bitumen are a result of physical entanglement and reinforcement afforded by the copolymer molecules. Above all, the molecules yield elastic properties of the binder.

The main objective of using polymer additives in bituminous mixes is to provide a cost effective solution in improving the resistance to permanent deformation of the surfacing materials under extreme loading conditions [2][3]. Secondary benefits in terms of resistance to fatigue cracking or better load spreading ability may also be gained with some of the additives. At present, there is a wide range of polymer additives available on the market, the most common types that are being used include [4];

- a. Latices of Styrene Butadiene Rubber (SBR).
- b. Block copolymer of Styrene Butadiene Styrene (SBS).
- c. Copolymer of Ethylene Vinyl Acetate (EVA).
- d. Natural rubber.

The additives may be supplied as factory blend modified binders or in the form of granules, pellets or powders for field blending.

Button and Little [5] reported that a small quantity of EVA copolymer increased the softening point and improved the temperature susceptibility of the binder. In addition, EVA modified binders improved the resistance to permanent deformation and modulus of rolled asphalt without adversely affecting laboratory fatigue behaviour [2]. Full-scale trials have also shown that EVA copolymers improved the workability of rolled asphalt [2].

Valkering and Vonk [3] showed that SBS modified binders markedly increased the deformation resistance of asphalt mixes in the Laboratory Test Track, attributing the improvements to the combined effect of increased viscosity and elastic behaviour of the binder. EVA modified binders, however, were not only found to be less effective than the SBS modified binders but also lose ductility and elastic recovery performance much more rapidly after the Rolling Thin Film Oven test (RTFOT).

Conversely, Denning and Carswell [2] concluded that based on laboratory investigations on a few types of polymers which include a synthetic rubber cross-linked in-situ, SBS block copolymers and EVA copolymers, the EVA copolymers were not just the most effective in improving resistance to permanent deformation but also simplest to use.

Elsewhere, an EMA polymer has been shown to improve the resistance to permanent deformation of the Marshall design asphaltic concrete in a full-scale trial by a factor of 10 [6].

## **2.2.2 Improvements of Skeletal Structure of Aggregates**

Resistance to shear of bituminous mixtures is a function of cohesion and internal friction in the mixtures. Cohesion is obtained in the mortar component – the mixture of bitumen and aggregate finer than 2 mm. It is mainly dependent on the quantity and properties of the bitumen. Internal friction is obtained from a firm contact between the coarse (larger than 2 mm) aggregate particles.

In conventional asphaltic concrete as currently specified in the Standard Specification for Road Works of JKR [7], any firm contact between the coarse aggregate particles does not exist. The quantity of mortar is so large that the coarse aggregate particles in the mixture are always spread apart. The shear resistance is therefore mainly dependent on the cohesion and some internal friction that may exist between the fine aggregate particles in the mortar. Attempts to improve the shear resistance of the current asphaltic concrete wearing course ACW 20 [7] are therefore restricted to improving these two properties ie. cohesion and internal friction. However, these properties can be improved only to a limited extent.

### **Improving the cohesion**

Harder bitumen can be used in order to increase the cohesion but will make the mixture more sensitive to cracking. The use of bitumen modifiers can help to a certain extent but it is not really the solution of the shear induced problem.

### **Improving the internal friction**

The internal friction in the mortar is dependent on the existence of a firm contact between the fine aggregate particles in the mortar. The use of crushed fine aggregate or quarry dust instead of rounded natural sand will increase the internal friction as long as it does not seriously affect workability and compaction. If the mortar is saturated with bitumen, then the firm contact between the fine aggregate particles will be lost. However, this concern may lead to the design of mixtures with relatively low binder content. Such mixtures are rather sensitive to fatigue cracking as well as stripping and aging.

The solution is to use mixtures in which the shear resistance is mainly a result of the internal friction in the coarse aggregate particles. This means that the amount of the coarse aggregate must be large enough to ensure a stone skeleton in the compacted mixture.

In an article titled “Heavy Duty Asphalt Pavement – How do they look?” (source unknown), it is stated that the amount of aggregate passing 2 mm sieve shall in general be kept below 20 – 23%.

Mahboub and Allen [8] reported that large-stone asphalt mixes showed better stability, compressive strength, resilient modulus and creep properties, all of which contribute to improved resistance to permanent deformation.

Gaughan [9] suggested that the resistance to permanent deformation of conventional mixes could be improved by, to a certain limit, increasing the coarse aggregates content to

improve the aggregates skeletal structure and increasing the filler content to enhance the binder properties.

In a study carried out by Saskatchewan Highway and Transportation Department on premature pavement deformation due to heavy traffic loading (10), the agency found out that where rutting had occurred, the following properties were observed;

- i. Low air voids in the mixture.
- ii. Low air voids in the mineral aggregate.
- iii. High bitumen content.

Laboratory evaluation on the influence of bitumen on deformation by Alberta Transportation Department [10] showed that harder grade bitumen have some impact on deformation but mix design overshadow the impact. It was recommended that all the load from passing traffic should be transferred into the aggregate through point-to-point contact between the aggregate particles. If the bitumen, the main function of which is to waterproof and bind the aggregate particles, is forced to carry the load either due to high bitumen content or inadequate aggregate skeleton, excessive deformation is likely to occur.

More recently, a new mix design system called Superpave [11] has been developed in the United States. In this system, the aggregates are combined to form a design aggregate structure which is governed by a set of control points and a restricted zone.

### **3.0 PAST STUDIES BY JKR**

With the formation of Public Works Institute of Malaysia (IKRAM) arm of JKR in 1987, JKR then had several opportunities to evaluate various methods in mitigating permanent deformation of bituminous road surfacing in high stress areas. These methods can be broadly categorised into two;

- i. Bitumen modifiers.
- ii. Innovative bituminous mixes.

#### **3.1 Bitumen Modifiers**

##### **3.1.1 Chemcrete**

Chemcrete is a liquid additive composed of organo-metallic components dissolved in a softening oil. It promotes a polymerization reaction when added to bitumen resulting in the formation of stable Ketones and change to molecular structure of the binder. The presence of Ketones significantly increases resistance to bitumen ageing by oxidation, improves anti-stripping properties and reduces temperature and shear susceptibility. Based on laboratory studies, Daines et. al [12] reported that Chemcrete modified rolled asphalt showed improvements to permanent deformation and dynamic stiffness.

**Field Trial:** A full scale trial using Chemcrete was constructed in September 1988 between Km 31.3 from Kuala Lumpur on the Kuala Lumpur – Karak highway [13]. The section was considered to be appropriate for the trial as it included a climbing lane of uniform gradient along the complete length. A known quantity of bitumen was transferred from the storage tank to the pugmill through a static mixer. Chemcrete and flux oil, at 2% and 3% by weight of bitumen respectively, were introduced on the upstream side of the static mixer.

**Performance:** Three months after construction, however, the test section rutted and eventually stripped. It was later scarified and reconstructed [14]. The reconstruction did not provide the opportunity for detailed research. Nevertheless, monitoring in the form of rut measurements was carried out at regular intervals. Results showed that the control rutted to about 17 mm after 400 days whilst the Chemcrete rutted to about 14 mm after a similar period [15]. This indicates that the use of Chemcrete to improve resistance to deformation of bituminous mix has not been successful at that stage of the study. It was noted that there were a few major differences observed during the reconstruction relative to the first trial which could have prevented a similar premature failure;

- 4% Chemcrete was used in producing the modified binder for the binder and wearing course. Previously, the amount was 2%.
- While 3% flux oil was added to the modified binder of the wearing course in the first trial, none was used during the construction.
- Hydrate lime was used as a filler for the modified binder and wearing courses. While a similar type of filler was used in the previous modified wearing course, the filler of the modified binder course comprised of 1% cement and 1% quarry dust.
- In the first trial, the modified mixes were immediately laid upon arrival at the site. During reconstruction, however, laying was deliberately delayed for about 3 hours after mixing.

### 3.1.2 Polybilt

The opportunity to study the performance of an EVA copolymer and EMA came when a contractor, Binaan Setegap Sdn Bhd, in association with the polymers supplier, Exxon Chemicals, offered to finance a full-scale trial using Polybilt on the Kuala Lumpur – Karak highway in Malaysia. The offer was accepted by the Malaysia Highway Authority who then invited JKR to monitor the construction and performance of the trial.

There were various grades of Polybilt being developed and marketed by Exxon Chemicals as bitumen modifiers for use in road construction. Among these were Polybilt 100, 101, 103 and XCS 503. The polymers come in the form of free flowing pellets which when added to bitumen will absorb some of the lighter oils of the bitumen and consequently swell, creating polymer phases within the bitumen intermolecular structure. These phases grow with increasing polymer concentration. As the optimum polymer concentration is reached, these phases will interconnect to form a predominant continuous phase. Improvements in the binder properties and the subsequent bituminous mix are attributable to the presence of this continuous polymer phase. For the purpose of this trial, the supplier had chosen to use Polybilt 101 and Polybilt XCS 503.

**Polybilt 101:** Polybilt 101 is an EVA copolymer. It comes in the form of a mixture of spherical and flaky pellets. It is claimed to be the most suitable for road surfacings which need improved deformation characteristics.

**Polybilt XCS 503:** Unlike Polybilt 101, Polybilt XCS 503 is an EMA polymer and it comes in the form of spherical pellets. It has been developed to give good cohesive properties. It is claimed to be the most suitable for use in open graded mixes in tropical countries and exhibit good resistance to fatigue failure and age hardening.

**Field Trial:** The site selected for the trial was a 530 metre long climbing lane at Bukit Tinggi on the Kuala Lumpur – Karak highway. The climbing lane had a gradient of 8% and the average speed of the heavy vehicles using it was uniform and measured at 15 km/hr. A classified traffic count showed that the average daily number of heavy vehicles using the climbing lane was 1130. The majority of these vehicles had single rear axles which led to severe overloading. The experiment was designed to compare the relative performance of a conventional asphalt concrete wearing course made with penetration grade 80-100 bitumen with similar materials modified by the addition of the polymers. The amount of polymer to be added in was selected by the supplier and resulted in the following four test sections;

i.7.5% Polybilt 101    ii.5.0% Polybilt 101    iii.5.0% Polybilt XCS 503    iv.Control (no polymer)

The trial site was overlaid in the normal way using the various modified mixes in September 1989 [16][17].

**Performance:** The performance of the trial site was assessed by rut depth measurements taken at regular time intervals in the vergeside wheelpath. The results are shown in Figure 1. The results show that the control mix failed rapidly, reaching a nominal failure criteria of 15 mm in the vergeside wheelpath after only 170 days. The mixes modified with 5.0% and 7.5% Polybilt 101 performed better, apparently would reach the failure criteria after approximately 450 days had they not been milled off prematurely.

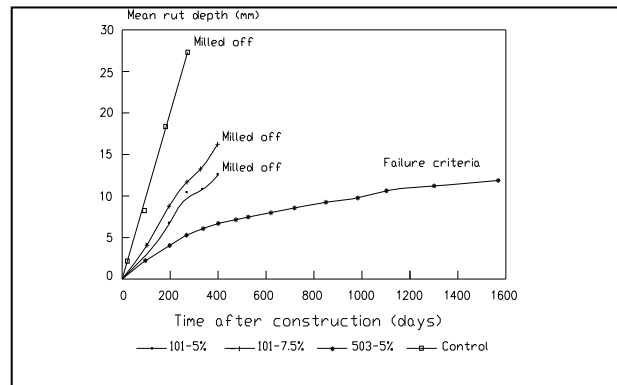


Figure 1. Rut depth progression in vergeside wheelpath.

The mixes modified with 5.0% Polybilt XCS 503 performed the best, having rut depths of only 11 mm in the vergeside wheelpath after 50 months. There were also no cracks in the surfacing after this time.

The most fundamental conclusion that can be drawn from this trial is probably the rate at which the control mix has deformed, reaching the failure criteria within six months. This type of failure is not untypical of asphaltic concrete mixes conventionally designed by the Marshall method and used in such a high stress area in Malaysia. This illustrates the urgent need to develop a surfacing material that can withstand the excessive loading conditions.

The mixes modified with Polybilt 101 performed better than the control, reducing the rate of deformation by a factor of two. However, even though it had a substantial effect on resistance to permanent deformation, its relatively short survival time means that it is unlikely to be cost effective. Increasing the polymer concentration to 7.5% did not appear to cause further improvements.

The mix modified with Polybilt XCS 503 has reduced the rate of permanent deformation by a factor of 10 compared to the control. This result would undoubtedly indicate that the use of this polymer would be cost effective for similar loading conditions.

### 3.1.3 Caribit-Plus

Caribit-Plus is a polymer modified bitumen. It is manufactured from selected grades of bitumen into which thermoplastic rubber of the type Styrene-Butadiene-Styrene (SBS) is incorporated by high shear mixing. It is claimed that when used in wearing courses, the binder offers advantages of reduced permanent deformation, longer fatigue life, allows use of thinner overlays and improved resistance to post compaction. The full-scale trial using Caribit-Plus was constructed together with Gilsonite as described.

### 3.1.4 Gilsonite

Gilsonite is a natural solid hydrocarbon containing a high concentration of high molecular weight asphaltene and nitrogen compounds. It comes as a free flowing granular solid that can be incorporated into the bituminous mix by pre-blending with bitumen or by direct addition during hot mix manufacture. Evidence from laboratory and field work demonstrated that Gilsonite offers improvements in stability, resistance to deformation, water stripping and ageing, and increases the pavement load carrying capability.

**Field Trial:** The trial sections of Caribit-Plus and Gilsonite were constructed in August 1990 on the Kuala Lumpur – Karak Highway [18][19] as described below;

**Caribit-Plus:** Caribit-Plus binder for use in the trial was imported from overseas. The modified binder had to be reheated to a temperature of about 160°C before being used. The temperature had to be raised gently to avoid causing a detrimental effect to the binder, needing about eight days before the desired temperature was reached. The optimum Caribit-Plus binder content in the ACW 20 mix was designed at 5.0% by the supplier as opposed to 5.95% using conventional bitumen. The test section was constructed in two different ways as requested by the supplier; the first 100 metres was constructed in two layers, 40 mm laid on

top of a 25 mm layer while the next 100 metres was laid and compacted in one lift to a thickness of 65 mm.

**Gilsonite:** The batching plant produced 1300 kg of mix per batch. For each batch, two 3.9 kg bags of Gilsonite powder amounting to about 10% by weight of the bitumen, were added directly into the pugmill. The quantity of bitumen was reduced by 7.8 kg per batch thus giving a resultant bitumen content of 5.35%. Mixing period in the pugmill was prolonged by 20-25 seconds as requested by the supplier. The entire 200-metre test section was constructed to the normal contractual procedures using Gilsonite modified ACW 20 mix.

**Performance:** It was reported that the two test sections had cracked considerably even though the mean rut depth in either section was less than 8 mm after 600 days. The cracks were first observed in February 1991, six months after construction, mostly as single type. Since then, the cracks had propagated to larger areas and increased in intensity with time.

### 3.1.5 Sasobit

Sasobit is a long-chain aliphatic hydrocarbon. It is produced in South Africa from coal gasification in the form of tiny bead off-white in colour. Its melting point is about 100 C and it is completely soluble in bitumen at temperatures in excess of 115 C. It forms a homogenous solution with bitumen on stirring and produces a marked reduction in the bitumen viscosity. However, at temperatures below its melting point, Sasobit forms a lattice structure in the bitumen which is the basis for the structural stability of asphalt containing Sasobit.

**Field Trial:** Resurfacing of Route 1 between km 4 and km 5 from Seremban towards Mantin was carried out in September 1999 incorporating penetration grade 80 – 100 bitumen modified with 4% Sasobit [20]. The gradient of the selected climbing lane was approximately 6% and traffic volume was 890 cv/lane/day. The performance of the Sasobit test section and adjacent control section was monitored in terms of rutting and cracking over a time interval.

**Performance:** Although the Sasobit test section did indicate improved resistance to rutting as compared to the control, higher percentage of area of cracks was observed in the test section. In addition, ravelling had also occurred within the test section.

### 3.1.6 Natural Rubber

Trials using rubberised bitumen were initiated in 1950s when 100 yards of road between Kota Bharu and Kuala Krai was laid with 5% rubber powder. Following that, several other trials were laid in the states of Kedah, Perlis, Kelantan, Johor, Negeri Sembilan and Melaka. Unfortunately, none of these trials was monitored closely and as such no details are available.

Chew and Ting [21] reported a full-scale experiment that was carried out in late 1968 at two sites; KL – Seremban road at mile 17 - 18 and KL – Bentong road at mile 14 ¼ - 14 ½. Penetration grade 80 – 100 bitumen was used with 1.5% and 3% natural rubber latex. The trial sections however failed after three years due to rapid increase in traffics. At that point, JKR concluded that there was nothing to be gained by adding rubber into road surfacing.

With the formation of Public Works Institute of Malaysia (IKRAM) in 1987, a more concerted effort was given by JKR in the research work. A collaboration with Rubber Research Institute of Malaysia (RRIM) was solicited to tap expertise from local rubber researchers. A number of field trials were subsequently conducted under the collaborative study, the more notable ones are briefly described below.

**Klang Trial :** The first opportunity to construct a full-scale road trial under the collaborative study came in 1988 during the construction of a new dual carriageway in Port Klang. Natural rubber latex at 2% concentration had been proposed for the trial. The plant engaged to manufacture the bituminous materials was a continuous drum mixer. It had no facility for injecting latex directly into the mixing drum, therefore the rubber was preblended with the bitumen in the bitumen storage tank prior to mixing. TRRL Road Note 36 [22] specifies that a propeller type stirrer should be used. However, the plant did not have this facility so the contractor proposed to blend the latex into the bitumen by circulating the binder from one

storage tank to another by means of an external circulating pump. This method of blending was not satisfactory as the resulted blend of rubber and latex was not uniform. Nonetheless, some latex which appeared to have blended with the bitumen seemed to have improved the performance of the modified binder in that the aging of the top few millimetres of the surfacing appeared to be less than in the control and the stiffening effect of the rubber additive reduced FWD deflections more than in the control [23][24].

**Rembau Trial :** In December 1993, another trial was constructed on Route 1, between Rembau and Tampin. The 1 km stretch was divided into eight different test sections. Three forms of rubber were used; latex, tyre shaving and rubber powder from rejected domestic gloves. Dry process of mixing was adopted whereby a measured amount of the rubber additives was manually added into the pugmill. Dense graded asphaltic concrete and bituminous macadam, and open graded porous asphalt were constructed in the trial. Up to May 1997, when the last monitoring was carried out, the control section showed an average rut depth of 2.3 mm while the rest of the sections had either zero or negligible rut. All sections had not cracked. Indirect Tensile Strength (IDT) tests carried out on cored samples indicated consistently that rubberised mixes had higher stiffness modulus compared with the conventional mix.

**KLIA Project :** The experience mentioned above had led IKRAM to propose the use of rubberised bitumen in the prestigious KL International Airport (KLIA) project. Specification Series 900 of the KLIA project included the preparation of rubberised bitumen in compliance with TRRL Road Note 36 for use in the construction of wearing course of the perimeter road. As recommended by RRIM, high quality grade natural rubber powder with specific vulcanizate properties was specified. Superpave performance grade PG70 in compliance with AASHTO MP1 – Standard Specification For Performance Graded Asphalt Binder [25] was specified for the rubberised bitumen. A total length of approximately 50 km of the wearing course of the perimeter road was successfully constructed using rubberised bitumen blend of crumb rubber from old tyres.

## **3.2 Innovative Bituminous Mixes**

### **3.2.1 High Compaction Mix**

Research works carried out based on the third method of the End Specification of assessing the resulting density of bituminous materials by the IKRAM have produced an innovative road pavement layer termed as the High Compaction Mix (HCM). It is basically a bituminous road surfacing mix which is designed, laid, compacted and tested using improved procedures to achieve a consistently high level of compaction. Unlike conventional mixes for wearing course, the HCM is composed of a coarser aggregate gradation with a substantial reduction in binder content. High level of compaction is achieved by increasing the compactive effort and within limits, the temperature at which compaction is carried out. The HCM uses current materials and construction equipment available in road construction. Higher compactive efforts may incur a slight increase in cost but this would be insignificant to the overall cost of producing and laying the mix.

**Field Trial:** To test its performance, a section using the HCM was constructed together with other sections using bituminous surfacing fortified with different bitumen additives. A control was constructed using an asphaltic concrete mix according to the current standard specifications for road works of JKR [7].

The trial was constructed in August 1990 on the Kuala Lumpur – Karak highway on a climbing lane having a gradient of 8% and was monitored periodically [26][27]. The main parameters monitored were rutting and cracking.

**Performance:** It was observed that the control test section failed very rapidly by rutting, reaching the failure criteria of mean rut depth of 15 mm after only 6 months and was subsequently milled off. The sections constructed using modified binder showed only slight rutting with the mean rut depth for each section being less than 10 mm after 2 years. The results of periodic rut measurements are shown in Figure 2.



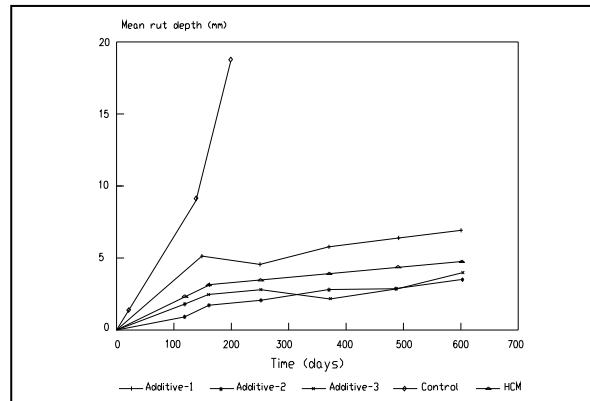


Figure 2. Mean rut depth in wheelpath.

However, other mode of surface distress namely cracking appeared to prevail. The cracks were first noticed approximately six months after construction. Since then, the cracks had propagated to larger areas and increased in intensity. Visual inspection of the cores taken from the affected areas showed that the cracks originated from the top. The distress could probably be due to the hardening of more viscous modified binder to a level whereby despite being more tolerant to traffic induced deformation, it was less resistant to induced tensile strain under high traffic loading. Figure 3 shows the crack propagation with time.

Without binder additives, the HCM section showed equivalent high resistance to deformation. The section had also shown less cracking as compared to the other sections.

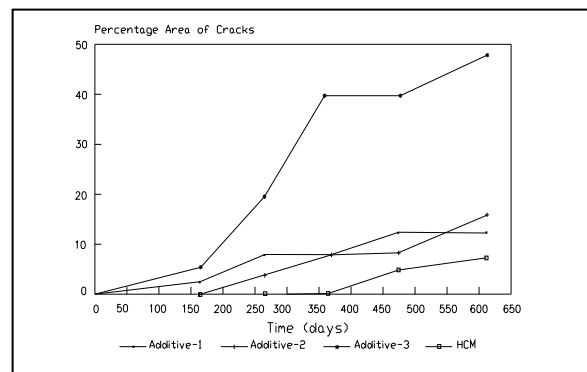


Figure 3. Percentage area of cracks.

### 3.2.2 Superpave Aggregate Structure

Asphaltic concrete, as specified in JKR/SPJ/1988 [7], is a form of dense-graded bituminous mixes with aggregate gradation based on specified envelopes. The appropriate quantity of bitumen required to bind the aggregate particles is determined using the Marshall method. Its inception in 1970s in Malaysia was preceded with recipe type dense bituminous macadam. With a perceived requirement to improve durability, the aggregate gradation of asphaltic concrete in Malaysia has been amended several times with an inclination to produce finer mixes with higher bitumen contents. Recent development in overseas saw the introduction of a variety of special purpose mixes such as the open-graded porous asphalt and the gap-graded stone mastic asphalt where the addition of polymers or cellulose fibers are prerequisite. However, the additional processes and materials required to produce the mixes make the products more expensive. More recently, a new mix design and analysis system has been developed in the Strategic Highway Research Program (SHRP). This largest ever asphalt research program was established by the United States Congress in 1987 to improve specifications and test methodology of bituminous mixes. The program concluded in March 1993, costing the US Federal Government US\$150 million. The final product of the program is a new mix design system referred to as Superpave, an acronym for 'Superior Performing Pavement'.

### 3.2.2.1 Aggregate gradation of Superpave

In Superpave, the aggregates are combined to form a design aggregate structure which is governed by a set of control points and a restricted zone [28]. The gradation curve shall pass through the control points and avoid the restricted zone. If the restricted zone is violated, the aggregate structure may possess a weak aggregate skeleton which results in tender mixes. Tender mixes are difficult to compact during construction and offer reduced resistance to deformation by traffic. For high-traffic pavement, it is recommended that the gradation passes below the restricted zone.

### 3.2.2.2 Comparison of aggregate gradations

The following aggregate gradations of wearing course as extracted from JKR/SPJ/1988 (7) are chosen to be compared with Superpave;

- i. ACW20 (Table 4.8, Clause 4.2.4, JKR/SPJ/1988)
- ii. BMW14 (Table 4.12, Clause 4.2.5, JKR/SPJ/1988)

In Australia, a new specification called the National Asphalt Specification [29] has recently been produced by the Australian Asphalt Pavement Association (AAPA), in January 2000. The following aggregate gradation for medium and heavy traffic wearing course respectively as stipulated in the new Australian specification are selected for comparison with Superpave.

- i. AC10 (Table 3.2.1, Clause 3.2, National Asphalt Specification, Australia)
- ii. AC14 (Table 3.2.1, Clause 3.2, National Asphalt Specification, Australia)

**Malaysian ACW20 versus Superpave :** The master envelope of ACW20 does not exactly fit into the control points particularly at 10 mm and above. It does not have the characteristic S – shape of Superpave grading curve. Grading curves of ACW20 pass above the restricted zone. About 26 – 38% passes 2 mm sieve for Superpave grading curves that pass below the restricted zone as compared to 38 – 55% for ACW20.

**Malaysian BMW14 versus Superpave :** BMW14 is coarser than Superpave in the range 0.5 to 5.0 mm. Grading curves of BMW14 pass below the restricted zone. About 20 – 38% passes 2 mm sieve for BMW14.

**Australian AC10 versus Superpave :** AC10 fits nicely into the control points and it may avoid the restricted zone with careful selection of gradation curves that pass below the zone. About 32 – 40% passes 2 mm sieve for both Superpave and AC10 grading curves that pass below the restricted zone.

**Australian AC14 versus Superpave :** AC14 fits nicely into the control points but it is more likely to violate the restricted zone (see Note). About 28 – 35% passes 2 mm sieve for both Superpave and AC14 grading curves that pass below the restricted zone. The aggregate gradation curves for both medium and heavy traffic as proposed in the Australian National Asphalt Specification fit nicely into the control points and have the characteristic S – shape of Superpave grading curve.

*Note: It was reported by Kandhal and Cooley [30] that based on the recommendations from the just-completed NCHRP Project 9-14 “Investigation of the Restricted Zone in the Superpave Aggregate Gradation Specification”, the restricted zone was expected to be deleted entirely from Superpave.*

## 4.0 OTHER ALTERNATIVES

### 4.1 Interlocking Concrete Block Pavement

Interlocking concrete block pavement consists of a surfacing layer of concrete paving blocks on a bedding sand spread on a properly prepared bituminous base or milled existing

bituminous surface. The design method of such pavement is described in the Cement and Concrete Association of Australia Technical Note TN 40 "Design of Interlocking Concrete Pavements for Road Traffic" [31]. This shall be read in conjunction with TN 41 "Specification for Construction of Trafficked Interlocking Concrete Pavements" [32]. In addition, there is also TN 42 "Design of Interlocking Concrete Pavement for Heavy Duty Industrial Vehicles" [33].

Accelerated trafficking tests and observations of in-service interlocking concrete block pavements have shown that the pavements progressively stiffen and tend to develop a condition of 'lock-up' under traffic. Once this 'lock-up' is achieved, the pavement attains a stable equilibrium condition which is then unaffected by the volume of traffic or the magnitude of single wheel loads within the range 2 to 7 tonnes. The interlocking pavement then acts as a structural layer rather than merely as a wearing course.

Since the blocks are available in a variety of shapes and colours, they offer delineation of areas such as road junctions by use of contrasting coloured units. In addition, the noise differential which interlocking concrete block pavements produce with respect to adjacent conventional pavements can provide a safety measure to alert motorists at the road junctions.

## **4.2 Stone Mastic Asphalt**

SMA is a dense, gap-graded hot-mix asphalt with a large proportion of coarse aggregates and a rich bitumen-filler mastic. The coarse aggregates, through point to point contact, forms a high stability skeleton with good internal friction and aggregate interlock to resist load-induced shear. In comparison, any firm contact between the coarse aggregates of asphaltic concrete does not exist. The quantity of mortar is so large that the coarse aggregates in the mix are simply spread apart.

To provide resistance to rutting, SMA relies on a stone-on-stone skeleton. The point-to-point contact achieved in the stone skeleton provides an internal friction throughout the overlay that resists load-induced shear. The stone skeleton is filled and held together with a mastic compound of the bitumen, the sand fraction and aggregate fines. The mastic is rich in bitumen and voidless so it provides a durable surface that is resistant to cracking. The stone skeleton must accommodate the mastic without disrupting the point-to-point contact of the coarse aggregate or the overlay will be susceptible to rutting.

To achieve the stone-to-stone skeleton, an aggregate blend rich in coarse aggregates is essential. The coarse aggregates (retained on 2 mm sieve) makes up 70% to 80% by weight of the aggregates; the maximum size may vary from 5 mm to 20 mm. Filler material (passing 75  $\mu$ m) accounts for another 8% to 13% by weight. The fine aggregates comprising material of size between 75  $\mu$ m and 2 mm makes up only 12% to 17% [34].

The bitumen, fine aggregates, filler and optional stabilisation additive form a mastic binding the skeleton of coarse aggregates together.

After placement and compaction, SMA has a coarse open texture characterized by good coarse aggregate macrotexture that provides excellent skidding resistance.

The mix was originally produced as a proprietary product to resist the wear of studded tyres but recognition of its excellent performance led to its standardization in the German Technical Specification in 1984. Today, it is the most widely used type of wearing course on the road network in Germany. It also has been adopted and used extensively in many other countries including Sweden, Denmark, Netherlands, Belgium, France, Switzerland, Japan and more recently in some parts of the United States [35].

SMA has been found to be very deformation resistance due to its aggregate skeleton structure [36]. The voids in the stone matrix are filled with a mastic of bitumen/crushed sand/filler to which fibres may sometimes be added to prevent binder drainage. The excellent structural properties of the material are derived from its aggregate skeleton and the fibers are used primarily as a bitumen carrier to increase the thickness of the binder coating and thereby reducing oxidation. Fibres also act as a micro-reinforcement of the mastic and improved stability of the mix and further enhance the rut resistance of the mix.

SMA has high durability and resistance to age hardening by virtue of its low void content and thick binder film. Consequently, it is resistant to premature cracking, ravelling and damage by moisture.

### 4.3 Semi-Rigid Surfacing

Semi-rigid surfacing consists of an open-graded asphalt with the air voids completely filled up with a special cement-based mortar. It combines the flexibility of asphalt with rigid mortar, the latter provides high compressive strength and wear resistance as well as high durability in aggressive environments.

The open-graded asphalt is usually laid one day in advance and then filled up with the mortar the following day to prevent any residual heat from causing accelerated hardening of the mortar.

Semi-rigid surfacing is being widely used on the bus lanes in the city of Kuala Lumpur whereby the usage of the expensive mortar in aggressive environments attributed mainly by hot fuel spillage from the buses is deemed appropriate. However, its high cost (approximately RM100 per m<sup>2</sup> as compared to RM10 per m<sup>2</sup> for conventional asphaltic concrete overlay) could pose a hindrance to its application in other areas where the environment is not similarly aggressive.

## 5.0 CONCLUSIONS

- i. Conventional asphaltic concrete which is designed by the Marshall method has been shown to fail very rapidly by rutting in high stress areas. Typically, the rut depth would reach approximately 15 mm after only 6 months.
- ii. Incorporation of bitumen modifiers to the asphaltic concrete indicates improved resistance to rutting. However, other mode of surface distress namely cracking appears to prevail. The cracks could probably due to the hardening of the more viscous binder to a level whereby despite being more tolerant to traffic induce deformation, it is less resistant to induced tensile strain under high traffic loading. The bitumen modifiers which have been shown to exhibit this characteristic in the road trials are Caribit-Plus, Gilsonite and Sasobit.
- iii. Some types of bitumen modifiers have been shown to marginally improve resistance to rutting. These are Chemcrete and Polybilt 101.
- iv. The performance of natural rubber as bitumen modifier has thus far not been proven in high stress area.
- v. The bitumen modifier which has been shown to perform the best thus far is the Polybilt XCS 503. Its test section only rutted to about 10 mm after 50 months. In addition, there were no cracks in the test section after that period.
- vi. It has been shown that an innovative bituminous mixture called the High Compaction Mix (HCM) exhibits high resistance to rutting equivalent to the mixtures having bitumen modifiers. The mixture which is designed, laid, compacted and tested using improved procedures to achieve a consistently high level of compaction has also shown resistance to cracking which is better than the modified mixtures.
- vii. Development of bituminous mixtures consisting of rigid aggregate skeleton structure with firm interlocking between coarse aggregates may also offer improved resistance to load-induced shear. Such mixtures are Stone Mastic Asphalt (SMA) and Superpave.
- viii. Interlocking concrete block pavement has also been proven to resist load-induced shear particularly at main junctions. In addition, its contrasting colour and rough surface texture duly provide a safety measure at the junctions.
- ix. High compressive strength and improved durability in aggressive environments of semi-rigid surfacing is attributed to the specially prepared cement-based mortar that fill up the air voids of the open graded asphalt.

## 6.0 RECOMMENDATIONS

- i. The key to building rut-resistant bituminous layers is to design and build a structure where aggregate particles carry the load, and bitumen waterproofs and binds the aggregate particles. Therefore, the aggregate grading structure shall be formulated such that all the load from passing traffic should be transferred into the aggregate through point-to-point contact between the aggregate particles. Shear resistance shall mainly be the result of the internal friction in the

coarse aggregate particles. This means that the amount of the coarse aggregate must be large enough to ensure a stone skeleton in the compacted mixture.

- ii. The recommended aggregate grading structure is the Superpave aggregate grading whereby the content of coarse aggregate is considerably higher than in the conventional asphaltic concrete wearing course ACW20. For Superpave grading of nominal size 12.5 mm and that passes below its restricted zone, the amount of aggregate passing through the 2 mm sieve is limited to between 28 – 38% as compared to 38 – 55% for the conventional asphaltic concrete. The proposed aggregate grading envelope similar to Superpave grading of nominal size 12.5 mm has been included in the new standard specification for roadworks of JKR which is being jointly prepared by Cawangan Jalan and Cawangan Pakar & Kejuruteraan Awam.
- iii. Unless the Superpave aggregate grading has been proven to perform satisfactorily in high stress areas with either penetration grade 70 – 100 or 50 – 70 bitumen, the mixture shall incorporate bitumen modifiers to enhance the rheological properties of the binder. The modified binder shall be of performance grade PG 76 or higher in compliance with AASHTO Standard M320-02.
- iv. As an alternative to the mixture as described above, Stone Mastic Asphalt with the amount of aggregate finer than 2 mm limited to between 20 – 30% shall be used. Draft standard specification for Stone Mastic Asphalt is being jointly prepared by Cawangan Jalan and Cawangan Pakar & Kejuruteraan Awam.
- v. Interlocking concrete block pavement shall be used at specific locations such as main junctions. Besides providing a structural layer that is able to resist load-induced shear, it also presents an additional benefit in terms of safety measure at the junctions by virtue of its contrasting colour and rough surface texture.

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